Exploitation of Thermal Signals in Tidal Flat Environments

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LONG-TERM GOALS

The overall goal is to identify and understand the physical processes that shape and change coastal environments. Emphasis is on the application of remotely sensed infrared signals that can be compared with in situ observations and assimilated within predictive models. In tidal flat environments, the major goals are to detect geotechnical properties (e.g., sediment strength), morphologic features (e.g., channels), and related hydrodynamic events (e.g., plumes).

OBJECTIVES

The primary objective of these joint efforts is to develop thermal methods for improved monitoring and prediction of tidal flat environments. Specific objectives are to:

- Test and apply the Lovell [1985] hypothesis for the porosity of sediment as a function of thermal conductivity,
- Refine methods to estimate inter-tidal bathymetry using sequential waterline detection,
- Quantify the importance of channel networks, and
- Determine the feasibility of detecting buried budgets using infrared sensing.

APPROACH

The technical approach is to conduct field experiments using simultaneous remote and in situ observations of thermal signals in tidal flat environments (Figure 1). Infrared images collected from airborne and fixed platforms are being used to study surface temperatures, which are then related to an

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array of interior (sediment and water) temperature measurements. The experiments are designed to study geotechnical, hydrodynamic, and morphologic aspects of tidal flats.

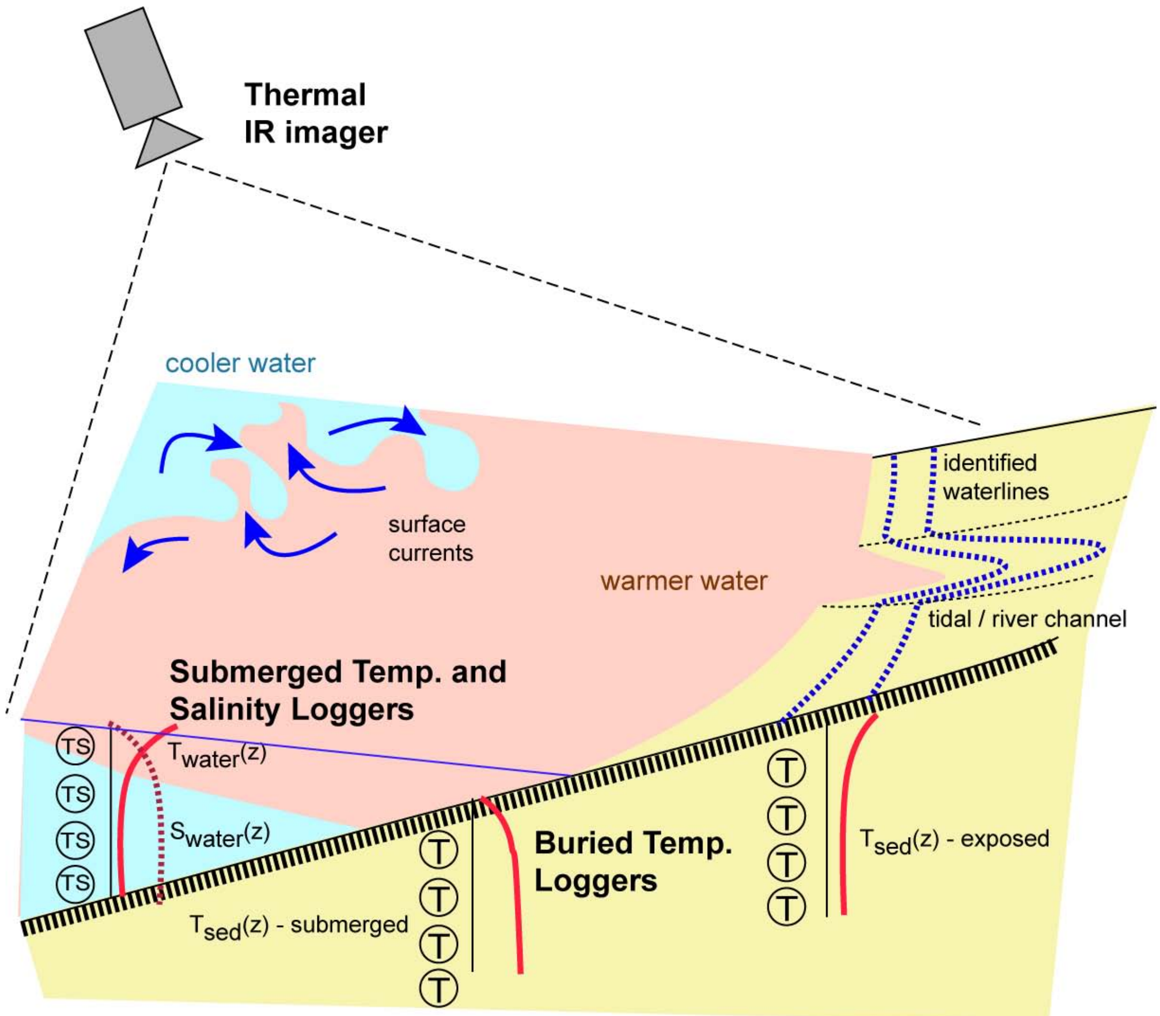

Figure 1. Schematic diagram showing infrared and in situ measurements of thermal signals in a tidal flat environment. The infrared measurements of surface temperature are made from a tower, aircraft, or helikite, and the in situ measurements of interior (both water and sediment) temperature are made from anchored platforms.

The sediment temperature data is being analyzed using Lovell's [1985] empirical formula for the fractional porosity n (i.e., the water content) of saturated sediments as a function of thermal conductivity k, where

$$k = k_s^{(1-n)} k_f^{(n)},$$

and k_s, k_f refer to the thermal conductivities of the solid and fluid, respectively. Assuming a 1D heat balance, the temperature T at the surface of the sediment (measured using infrared imagery, see Figure

1) diffuses downward in a vertical *z* profile (measured using buried loggers) at a time *t* rate governed by

$$d^2T/dz^2 = (c\rho/k)\, dT/dt,$$

where *k* is the thermal conductivity of interest, *c* is the specific heat, and ρ is the density [*Subramaniam and Frisk*, 1992; *Jackson and Richardson*, 2002]. Sediment porosity *n* will be estimated by finding the best-fit *k* at each location in the imagery and then will be compared with sediment samples collected by C. Nittrouer & A. Ogston (University of Washington).

Differential sediment and water surface temperatures are being used to detect waterlines and thereby estimate bathymetry. Waterlines extracted within plan-view infrared images at incremental tide stages will be interpolated to a Digital Elevation Model (DEM), similar to work with optical imagery in the nearshore [*Plant and Holman*, 1997] and infrared satellite imagery [*Ryu et al*., 2002]. Infrared imagery is well suited to shoreline identification due to the differential heating rate of sediment (fast) versus water (slow). We have increased the likelihood for quality data return and the general image resolution over satellite imagery by developing and deploying a small aircraft based thermal imaging system. Flying over the flats in a “lawn-mowing” fashion, we later georectify and mosaic the collected imagery for quantitative analysis. Bathymetry estimates will be compared against ground surveys collected during the pilot experiment.

The field data also will be used to quantify surface fluid velocities (e.g. using imagery [*Holland et al.*, 2001]) and estimate volume transport (using in situ data [*Wunch*, 1996]). These hydrodynamic quantities will be used to evaluate correlations with bathymetric features, such as channels, and will be compared with velocity measurements by S. Elgar & B. Raubenheimer (Woods Hole Oceanographic Institution), as well as S. Henderson (Washington State University).

Finally, the feasibility of detecting buried objects in exposed sediments using infrared sensing is being investigated. The approach is to use several objects of known thermal properties and determine a level of detection based on the depth of burial. Funds arrived for this effort at the end of FY09, and thus the investigation is still at a preliminary stage.

WORK COMPLETED

During the first part of FY09, we processed data from the summer 2008 field experiments, and presented our results at the AGU meeting in December 2008. During the second part of FY09, we successfully completed additional field experiments on the Skagit and Willapa Flats of Washington State, as shown in Fig. 2. The infrared measurements were made from a small plane (Cessna 172) and a “helikite” platfrom. The in situ measurements included arrays of temperature and pressure, as well as a metreological station and two accoustic Doppler current profilers. Instruments were successfully maintained from May to September 2009. Fig. 3 shows an example of the helikite deployed over a channel on the Skagit Flats. In addition, long term measurements (monthly survey flights and in situ temperature measurements) continued thoroughout FY09.

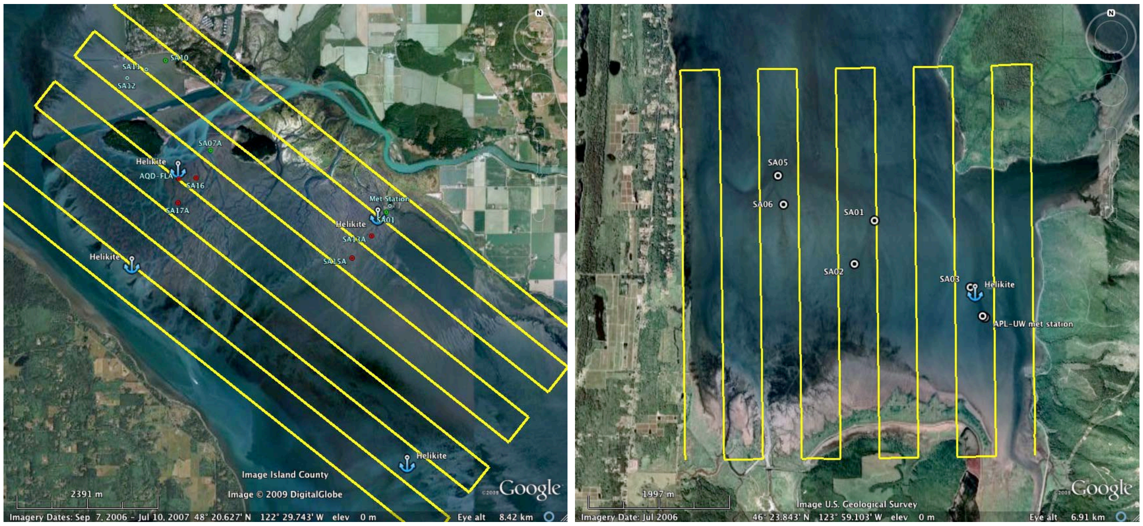

Figure 2. Google Earth images showing instrument locations (dots), overflight tracks (yellow lines), and helikite operations (anchors) during FY09 field experiments on the Skagit (left) and Willapa (right) Flats.

Figure 3. Example of field data collection on the Skagit Flats, using a helikite platform (upper left) deployed from a small boat (lower right). Our metreological station is in the foreground.

RESULTS

Analysis of 2008 data suggests that thermal signals can be used to remotely classify sediments and detect bathymetric features. The heat flux of exposed sediments is related to the composition and porosity of sediments. Sediments absorb heat during periods of strong solar radiation consistent with a 1D diffusion equation (Kim et al., 2007). As shown in Figure 4, an empirical model for diffusivity as a function of porosity (Lovell, 1985) successfully explains observations from the 2008 field campaigns. The sandy sediments have a much stronger response to heating, because the water content and porosity is lower, compared with the muddy sediments. Work is ongoing to relate the in situ conduction to the remote (infrared) sensing.

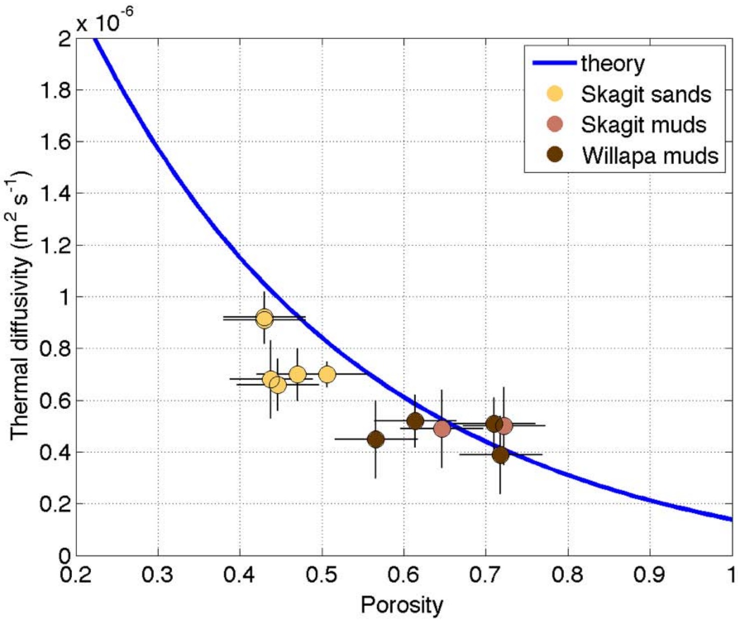

Figure 4. Thermal diffusivity of sediments versus porosity. Observed values (symbols) are consistent with an empirical model (curve) based on the vertical flux of heat.

Thermal images collected from overflights showed substantial gradients which can be exploited to measure large-scale bathymetry and circulation. Figure 5 shows examples of waterlines detected in geo-referenced infrared images, and bathymetry is estimated using a set of these images spanning a tidal cycle. Work progresses in developing the necessary routines to accurately mosaic the large number of airborne images. The time series will then be used to evaluate morphology, especially channel migration.

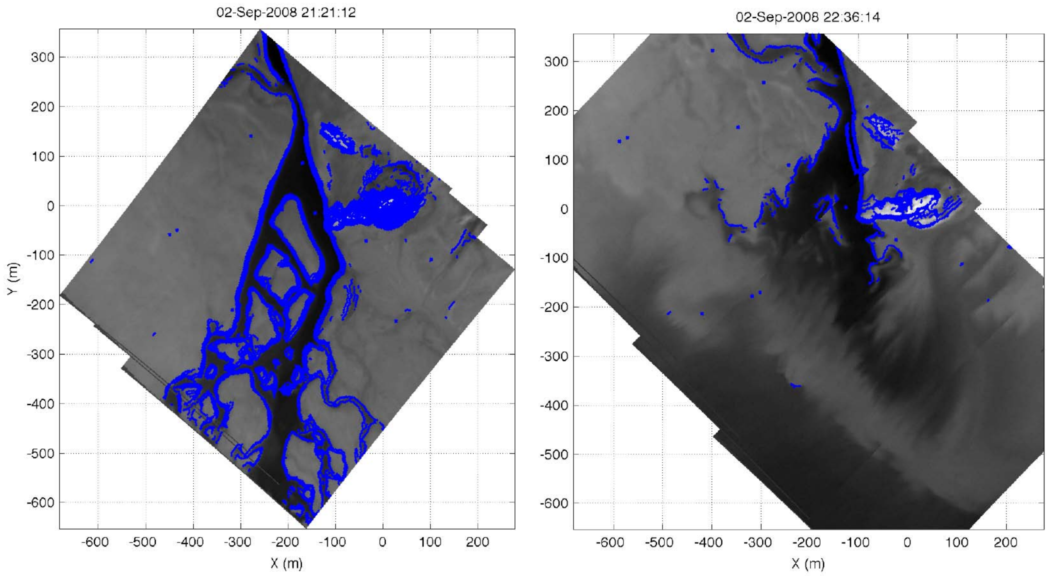

Figure 5. Waterlines detected in sequential airborne infrared images of the Skagit flats. In the later image (right) the leading edge of the flooding tide has a strong thermal signature of mixing.

IMPACT/APPLICATIONS

Improving techniques to remotely quantify tidal flat properties will allow for real time monitoring and safe operation in these environments. In particular, remote porosity estimation and channel detection will improve navigation for amphibious landings. In addition, evaluating the feasibility of remotely detecting buried objects may lead to new approaches to securing coastal landing zones.

RELATED PROJECTS

A new "helikite" imaging platform, developed under a DURIP (PI: Andrew Jessup), has dramatically improved spatial coverage of our infrared sensing by providing additional elevation and dwell time.

An ongoing MURI (Coherent Structures in Rivers and Estuaries Experiment, PI: Andrew Jessup) has provided infrared image data for proof of concept applications in the remote sensing of tidal flats (www.cohstrex.apl.washington.edu). Equipment and resources are shared with this project.

This effort is a contribution to the Tidal Flats DRI (www.tidalflats.org).

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